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Comprehending action in depicted paths: Evidence from the cognition of motion lines in visual narratives

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Abstract

Motion lines depict the path of a moving object, most popularly in comics. Some have argued that motion lines depict the “streaks” in the visual system when a viewer tracks an object (Burr, 2000). However, previous research has not used motion lines’ natural context of comics, has only depicted a limited number of actions (usually just running), and used only offline measurements like recall or ratings. Here, we compared panels in comic strips with normal motion lines and those depicting either no lines or reversed, anomalous lines. In Experiment 1, images with normal lines were faster than no lines, which were viewed faster than anomalous lines. In Experiment 2, ERPs showed that the absence of normal lines elicited a posterior positivity distinct from the frontal positivity evoked by the presence of anomalous lines. These results suggest that motion lines aid in the comprehension of depicted events as conventionalized visual signs.

Keywords: Motion lines; comics; visual language; events; motion; event-related potential; P600; P300.

Introduction

The depiction of motion poses a challenge for static images. Motion lines (also called action or speed lines) offer a solution to this issue by depicting the path of an action by attaching a line or series of lines to a moving object. These representations are especially pervasive in the visual vocabulary used in comics across the world (Cohn, 2013; McCloud, 1993).

Despite their origins in comics and drawings, researchers have claimed that the comprehension of motion lines originates in the biological foundations of vision. Since moving objects leave behind “streaks” in the visual system when a viewer tracks an object (Geisler, 1999), similar to a slow shutter speed of a camera, they argue that this residual could form the basis of our understanding about motion lines (Burr, 2000). Subsequent research has stressed that participants better understand or remember the direction of moving objects when they have motion lines than when they do not (Kawabe & Miura, 2006; Kim & Francis, 1998). Thus, under this interpretation, motion lines are a depiction of a basic aspect of human perception rooted directly in the visual system.

Nevertheless, this view has several limitations. First, motion lines are understood by blind people comparably to sighted people when presented using pictures with raised-lines similar to braille (Kennedy, Gabias, & Piertantoni,

1990). Second, people of cultures unfamiliar with this style of drawing have trouble understanding that these lines depict motion, though they do understand accompanying iconic representations (Kennedy & Ross, 1975; Winter, 1963). Third, interpretation of motion lines appears to change as people age (Carello, Rosenblum, & Groszofsky, 1986; Friedman & Stevenson, 1975; Gross et al., 1991). Younger children interpret motion lines as invisible yet iconic physical forces, such as wind, but recognize them as symbolic conventions as they grow older (Gross et al., 1991). Fourth, the representations of motion lines vary cross-culturally in comics and other drawing systems (Cohn, 2013; McCloud, 1993). Fifth, motion lines appearing in comics use a wide range of shapes, not only trailing laterally moving objects, including bouncing or spinning (Cohn, 2013; McCloud, 1993). Altogether, these findings suggest that motion lines do not originate in vision, but rather come from being a conventionalized graphic representation.

Nevertheless, research has mostly explored how motion lines graphically depict events and motion. In general, images with motion lines are thought to depict more motion than those with only postural cues (Brooks, 1977; Friedman & Stevenson, 1975; Gross et al., 1991; Ito, Seno, & Yamanaka, 2010; Kawabe & Miura, 2006). Also, more lines and longer lines lead to participants interpreting faster movement (Hayashi, Matsuda, Tamamiya, & Hiraki, 2012). Furthermore, motion lines that trail an object have been rated as more effective at depicting motion than a lack of lines, background lines, or lines moving in the wrong direction (Ito et al., 2010). One reason that motion lines facilitate comprehension and memory of depicted events more than when those same images lack motion lines is because they help clarify the interaction between entities that otherwise may remain underspecified (Brooks, 1977).

Despite the wealth of research investigating motion lines, especially with seriousness for their supposed implications on motion understanding, most of these studies remain limited. Even though motion lines appear ubiquitously in comics—and most studies emphasize this fact—few studies make use of this context and therefore do not reflect the full range of complexity and richness that goes into their comprehension. For example, stimuli typically use abstract circles or squares with a trailing motion line, focus specifically on the action of running, and/or only use straight lateral motions. However, in comics, motion lines

accompany nearly any type of depicted actions, not just a prototypical lateral running figure. Also, contrary to studies using only straight lines for lateral motions, motion lines in comics may be curved, may spiral around in a circle, or may depict points along a path. No previous studies have actually looked at the understanding of motion lines within the naturalistic context of a visual narrative *sequence* as opposed to an individual image.

Previous studies have also been limited in their experimental measurements and methodologies. Most studies of motion lines have focused on recall tasks and/or subjective ratings. Thus, despite the claims that motion lines may connect to basic perceptual processes (e.g., Burr, 2000; Kim & Francis, 1998), no studies have yet examined the online comprehension of motion lines. In order to overcome these limitations, we carried out two experiments that analyzed participants' comprehension of motion lines embedded in the naturalistic context of comic strips.

Experiment 1: Self-paced viewing

Experiment 1 used a "self-paced viewing" paradigm where participants progressed through a sequence frame-by-frame at their own pace. If motion lines facilitate event comprehension, panels with anomalous lines or no lines would be viewed more slowly than those with normal lines, consistent with previous offline measurements (e.g., Brooks, 1977; Ito et al., 2010). Specifically, slower viewing times for panels with no lines than normal lines would support that motion lines aid the comprehension of depicted events beyond postural cues.

Methods

Stimuli We created 90 6-panel long comic strips depicting explicit motion lines using panels from *The Complete Peanuts* volumes 1 through 6 (1950-1962) by Charles Schulz. Critical panels depicted several different events including running, jumping, throwing or kicking various objects (sports balls, sticks, paper, etc.), hitting balls (golf balls, croquet balls, baseballs), falling off of objects, moving down a slide, punching or running into objects, among several others actions. The actual depiction of motion lines varied based their natural original context, ranging from just one or two lines to many lines. They also varied in shape: straight and lateral, angled, vertical, curved, circular, etc. Such variety was chosen to cover motion lines' wide range of naturalistic contexts.

We created three types of critical panels (see Figure 1). Panels with "normal lines" used the original motion lines. Panels with "no lines" omitted the motion lines from the object. These lines were broken up and distributed to other parts of a frame to retain the same visual complexity as the original panel. Finally, "anomalous lines" reversed the lines from their original position to make the object appear to move in an incongruous motion to the action. Sequence types were counterbalanced into three lists with no repeating sequences, and also included 120 fillers.

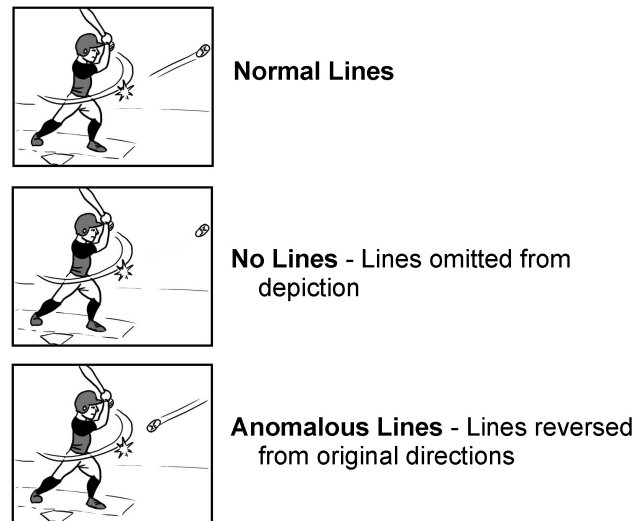


Figure 1. Critical panels from within a multi-image sequence with manipulation of motion lines to show either normal lines, no lines, or anomalous lines.

Participants Sixty-two experienced comic readers (35 male, 27 female, mean age: 24.03) from the Tufts University student population and surrounding neighborhoods were paid for their participation. All participants gave informed written consent according to Tufts University's Human Subjects Review Board guidelines. Comic reading fluency was assessed using a pretest questionnaire that asked participants to rate their habits for reading and drawing various types of visual narratives (for details, see Cohn, Paczynski, Jackendoff, Holcomb, & Kuperberg, 2012). Data from two participants were excluded from analysis because they had difficulty understanding the task.

Procedure Comic strips were presented frame-by-frame on a desktop computer screen. Participants controlled the pace of reading with a button press at each panel, and we measured how long each frame stayed on the screen. Trials began with a screen reading READY, followed by a fixation-cross (+). Then, each panel appeared on the screen one at a time until the end of the sequence. Here, a question mark appeared where they rated how easy the strip was to understand on a 1 to 5 scale (1=hard, 5=easy), at which point the next trial appeared. Prior to the experimental session, participants completed a practice list of five strips to orient them to the procedure.

Results

Our three-way ANOVA showed that viewing times differed significantly between critical panels of all motion line types in both the subjects analysis, $F(2,118)=11.30$, $p<.001$, and items analysis, $F(2,178)=5.63$, $p<.005$. As depicted in Figure 2, critical panels with Normal lines were viewed significantly faster than those with No lines, which

in turn were faster than those with Anomalous lines (all t s < -2.4, all p s < .05).

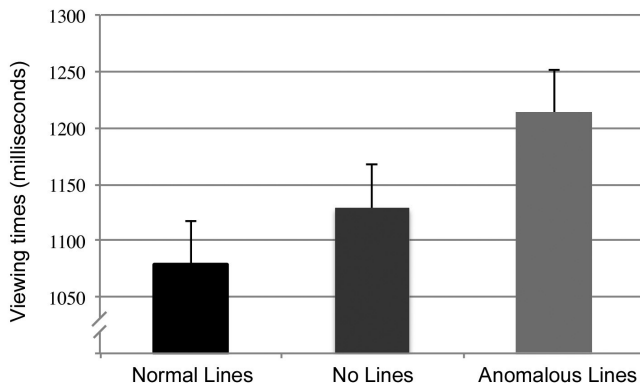


Figure 2. Viewing times to critical panels containing either 1) normal motion lines, 2) no motion lines, or 3) anomalous motion lines. Error bars represent standard error.

Discussion

This experiment explored the comprehension of comic panels containing normal motion lines, no lines, and reversed, anomalous lines. Slower viewing times were found to panels with no lines than normal lines, with even slower times appearing to panels with anomalous lines. These results suggest that motion lines aid in the comprehension of events, and that the violation of expected lines strains comprehension.

The longer viewing times to panels with no lines compared to normal lines support that readers found images with motion lines easier to comprehend than images without motion lines. These results are consistent with previous research suggesting that motion lines provide added understanding to motion beyond just postural cues (Brooks, 1977; Friedman & Stevenson, 1975; Gross et al., 1991; Ito et al., 2010; Kawabe & Miura, 2006). The longer viewing times to panels with anomalous lines than normal lines further supports that lines incongruous to their actions are harder to understand than when they fit the expected context. This result is consistent with Ito et al.'s (2010) study showing that no lines or reversed lines are rated as less effective at conveying motion than normal lines. These findings support that normal motion lines aid in the comprehension of events more than images without lines or incongruous lines.

The slowest viewing times appeared to panels with anomalous lines, not those with no lines, confirming that these representations were incongruous. These results differ from Ito et al. (2010), where no difference appeared in ratings between images with no lines and with reversed lines. They attributed their lack of a difference to these lines being viewed as iconic non-motion related representations, as based on participants' self-reported interpretations. However, such disparities may have arisen because of the reliance on subjectively determined ratings and stimuli that only depicted a silhouette engaged in a single action of

running. In contrast, the viewing times measured here clearly demonstrate the expected contrast between no lines and anomalous lines using more naturalistic stimuli depicting a variety of actions.

Overall, these results suggest that motion lines aid in the comprehension of events. However, do the longer viewing times shown to no lines compared to normal lines show that the presence of motion lines are facilitating processing or that the absence of motion lines inhibit comprehension? Also, can we attribute the longer viewing times to anomalous lines and no lines to the same underlying cognitive processes or are these qualitatively different effects?

While viewing times are able to provide a significantly better measure of comprehension than the subjective ratings or memory tasks used in previous research, they cannot provide the sensitivity to answer these outstanding questions. Thus, in Experiment 2 we measured event-related potentials (ERPs) to the same set of stimuli in Experiment 1. ERPs provide excellent functional and temporal resolution of the electrophysiological activity of the brain, and thus enable us to better answer these types of questions.

Experiment 2: Event-related potentials

Thus far, no studies have examined the comprehension of motion lines in the brain generally, nor using ERPs specifically. However, ERPs have been used to study visual narratives and real-world events, which often evoke the same effects when manipulated as other domains, particularly language. For example, though it was first studied in the contexts of semantic processing in language, images in visual sequences that violate the expected meaning of the narrative or events have consistently elicited N400 effects (Amoruso et al., 2013; Cohn et al., 2012; Sitnikova, Holcomb, & Kuperberg, 2008).

An additional positive-going ERP response also appears to manipulations of events, often following an N400 (for review, see Amoruso et al., 2013). This "P600 effect" was originally thought to index syntactic processing in language (Kuperberg, 2007; Osterhout & Holcomb, 1992). However, studies of event perception have found similar positivities to the viewing of actions where the events are not carried out correctly (de Bruijn, Schubotz, & Ullsperger, 2007), or where objects and/or hand position mismatch their corresponding events (Sitnikova et al., 2008; van Elk, Bousardt, Bekkering, & van Schie, 2012). Such results are important because motion lines bind together the elements in an action (Brooks, 1977). If P600 effects appear to incongruous component objects in an action, altering the binding between those components may elicit a similar brain response.

The notion that the P600 may index a general type of neurocognitive processing has been debated for some time, specifically in connection with the well-studied "P300" effects associated with unpredictable stimuli across modalities (e.g. Van Petten & Luka, 2012). Indeed, many of the action-related positivities discussed above have been

interpreted as a late onset P300 (de Bruijn et al., 2007; van Elk et al., 2012). The P300 is the oldest ERP component recognized as relevant to cognition (Chapman & Bragdon, 1964), and is commonly divided into two types. The P300a typically has a more anterior distribution and is thought to be sensitive to “novelty,” possibly connected to top-down monitoring of attentional mechanisms or the attentional demands initiated by aspects of a task (Polich, 2007). The more posteriorly distributed P300b is thought to be a response to “oddballs” with low probabilistic likelihood or a disconfirmation of expectations (Donchin & Coles, 1988), possibly reflecting attempts to update a mental model in memory (Polich, 2007).

If panels with no lines elicit a larger neural effect in the same direction as anomalous lines, it would suggest events were more difficult to understand. In contrast, if an attenuated response appeared to panels with normal lines compared with those with no lines, the presence of lines might facilitate event understanding. In addition, if panels with anomalous lines elicit a different pattern of effects than panels with no lines, this would suggest different brain responses.

Methods

Stimuli The same stimuli were used in Experiment 2 as in Experiment 1.

Participants Twenty-five comic readers from Tufts University and the surrounding area (8 male, 17 female, mean age: 19.9) participated in the study for compensation after giving their informed written consent. Participants were pre-screened to be right-handed English speaking comic readers with normal vision, no history of head trauma, and taking no neuropsychiatric drugs. Data from one participant was excluded due to artifact rejection exceeding 15%.

Procedure Participants sat in a comfortable chair facing a computer screen in a room separate from the experimenter and computers. Because a “flashing” effect of the white panels on the black screen could potentially induce blinks, we kept the lights on throughout the experiment. Participants began a trial by viewing the word READY, where they pressed a button on a keypad. A fixation-cross then appeared in the center of the screen, after which each panel of the sequence automatically appeared one at a time in that location, out of control of the participant. Each panel was onscreen for 1350ms, and an ISI of 300ms prevented a “flipbook” effect that made overlapping panels appear animated. Stimuli durations were based on the average viewing times in Experiment 1. After the final panel, a question mark cued participants to rate the sequence for how easy it was to understand (1=difficult to 5=easy). Ten prior

practice sequences acclimated participants to the procedure and stimuli. During the experiment, five breaks were given at designated intervals.

ERP Recordings ERPs were measured with 29 tin electrodes in an elastic cap distributed according to the International 10-20 system, plus additional left and right hemisphere sites. Electrodes below the left eye and next to the right eye recorded blinks and vertical and horizontal eye movements. Electrode sites were placed along the five midline sites (FPz, Fz, Cz, Pz, Oz), three pairs of medial sites (FC1/FC2, C3/C4, CP1/CP2), four pairs of lateral sites, (F3/F4, FC5/FC6, CP5/CP6, P3/P4), and five pairs of peripheral sites (FP1/FP2, F7/F8, T3/T4, T5/T6, O1/O2) on each hemisphere. These groupings formed the factors of Region in the statistical analysis. All electrodes were referenced to an electrode placed on the left mastoid, while differential activity was monitored in the right mastoid. A SA Bioamplifier amplified the electroencephalogram (EEG) using a bandpass of 0.01 to 40 Hz and continuously sampled at a rate of 200 Hz. Electrode impedances were kept below 10 k Ω for the eyes and below 5 k Ω at all other sites.

Results

Between 200 and 400 ms, a larger leftward posterior positivity appeared to panels with No Lines than those with Normal Lines localized to Occipital, Parietal, and Left Posterior regions (all $F_s > 4.36$, all $p_s < .05$). An additional anteriorly distributed positivity was greater to Anomalous Lines than No Lines in the Prefrontal region, $F(1,23)=4.56$, $p < .05$. No main effects appeared in this epoch between Normal Lines and Anomalous Lines.

Between 400 and 600 ms, a trending interaction for panels with Normal and No Lines was found in the midline regions, but without localization of this effect. In contrast, a frontal positivity was suggested by main effects at the Prefrontal and Left and Right Anterior regions, with a posterior positivity in the Left Posterior region (all $F_s > 4.6$, all $p_s < .05$) and trending differences in the Parietal region $F(1,23)=3.07$, $p=.093$. In addition, a frontal positivity appeared at the Prefrontal and both Left and Right Anterior regions (all $F_s > 4.5$, all $p_s < .05$), suggesting that panels with Anomalous Lines evoked a bilateral, frontally distributed positivity that was greater than both Normal and No Lines.

Finally, between 600 and 900 ms, Anomalous Lines showed a greater positivity than No Lines in Prefrontal, Central, Left Anterior, and Right Anterior regions (all $F_s > 3.8$, all $p_s < .065$). No significant differences appeared between panels with Normal Lines and No Lines or Anomalous Lines.

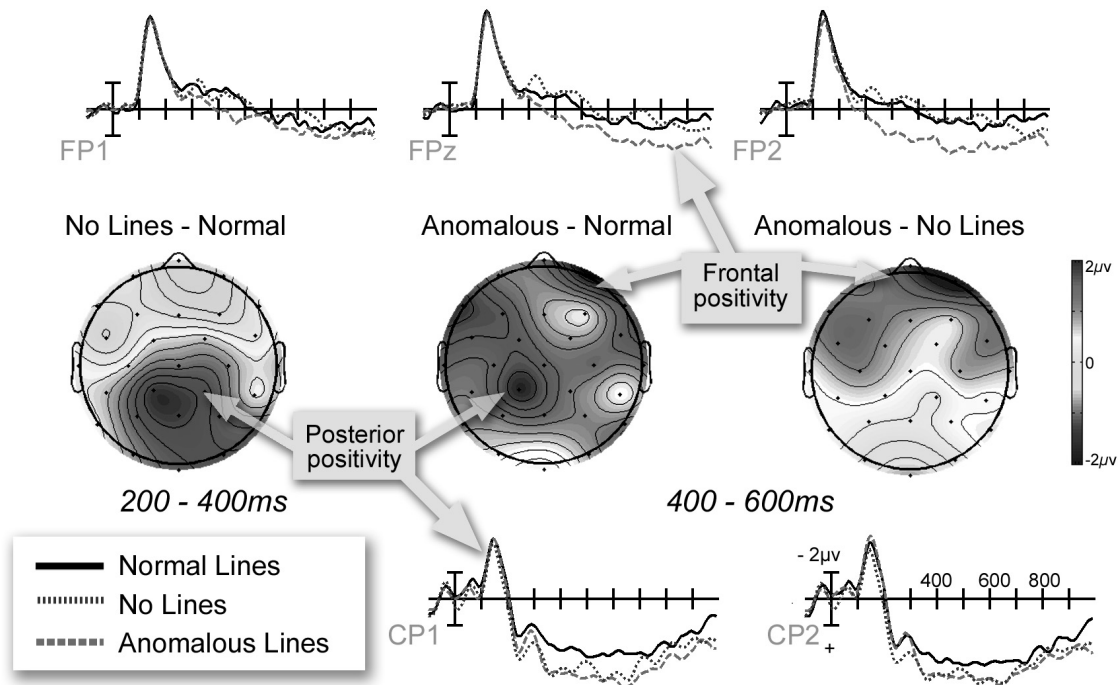


Figure 3. ERPs to critical panels with either normal motion lines, no motion lines, or anomalous motion lines.

All waveforms and scalp maps illustrating these distributions are illustrated in Figure 3.

Discussion

This experiment found two primary patterns of ERP effects. A posterior positivity between 200-400 ms occurred to the *absence* of normal lines, while a frontal positivity peaked between 400-600 ms to the *presence* of anomalous lines. Overall, we found no evidence of early ERP components associated with purely perceptual processing, as might be expected if motion lines were tied to “streaks” in the visual system. Rather, the later effects that we found suggest that comprehenders require additional processing to images with no lines or with anomalous lines above and beyond those with normal motion lines.

Our most noteworthy finding was a posterior positivity arising for panels that had no lines compared to those with normal motion lines. This positivity appeared to be greater to panels with no lines, rather than an attenuated negativity effect to panels with normal lines. These results imply that, to experienced comic readers, the absence of lines actually *impairs* a readers’ comprehension of an event, rather than the presence of motion lines *facilitating* event information.

One possibility is that this effect is tied to the posteriorly distributed “oddball” P300b, which typically arises to low probability or unexpected stimuli (Donchin & Coles, 1988). This would suggest that the absence of lines are inconsistent with comic readers’ expectations. However, this experiment did not involve a task when viewing these panels, which is associated with the P300b (Polich, 2007).

An alternative interpretation of this positivity could connect it with the P600 effect found in studies of language

and visual events (Kuperberg, 2007; Osterhout & Holcomb, 1992). In this view, the absence of lines makes events harder to understand because it no longer binds together the elements involved in the event. Omitting these lines may impair a viewer’s ability to bind together the component parts of the event, thus eliciting a P600 effect (Sitnikova et al., 2008).

Additionally, the presence of anomalous lines, when compared to both normal and no lines, evoked a frontal positivity. This effect may be connected to the typically anterior P300a, which commonly appears as a “novelty” response to surprising or unexpected stimuli (Polich, 2007). Anomalous lines should clearly be considered as “novel” or unexpected given their context.

General Discussion

In this study, we sought to overcome the limitations of previous research looking at motion lines by examining within the naturalistic environments of comic strip panels. We compared the online comprehension of panels that either had normal motion lines, no lines, or reversed, anomalous lines by measuring self-paced viewing times and ERPs. In Experiment 1, panels with normal lines were viewed faster than those with no lines, which were in turn faster than those with anomalous lines. In Experiment 2, we found two distinct patterns of ERP effects: a posterior positivity peaking between 200-400 ms appeared to panels with no lines compared to normal lines, and a bilateral anterior positivity peaking around 500 ms for panels with anomalous lines compared to those with both normal and no lines.

Together, these results suggest that the presence of motion lines in comic panels are important for the comprehension of events. Furthermore, both sets of results indicate that motion lines—used in diverse and varied contexts—are conventionalized signs understood and *expected* by comic readers to appear in the depiction of motions and events, and not tied to streaks left behind in the visual system (Burr, 2000). Rather, motion lines are conventionalized signs understood through experience, which is sensitive to both cultural (Kennedy & Ross, 1975; Winter, 1963) and developmental knowledge (Carello et al., 1986; Friedman & Stevenson, 1975; Gross et al., 1991).

An alternative account for the understanding of motion lines may instead tie them to the basic conceptual structure that underlies other expressive systems, such as language. This interpretation would be consistent with the idea that drawings are written in a “visual language” similar to underlying cognitive structure to spoken languages (Cohn, 2013). Just like different languages have words for expressing certain conceptualized meanings, visual languages use diverse ways to map graphic representations onto the same basic conceptualization of paths. Altogether, this study shows that research of phenomena in visual narrative can be useful to the study of a broad range of issues related to visual cognition, language, and the comprehension of events.

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